Local climate sensitivity of the Three Gorges Dam

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[1] Two simulations, control and land use change, were performed for an eight week period (2 April–16 May 1990) to determine the net sensitivity of the local climate around the Three Gorges Dam. The analysis indicates that the large reservoir acts as a potential evaporating surface that decreases the surface temperature, cools the lower atmosphere, decreasing upward motion, and increasing sinking air mass. Such sinking results in low level moisture divergence, decreasing cloudiness, and increasing net downward radiation, which increases the surface temperature. However, results indicate that evaporative cooling dominates radiative warming in this initial study. The strong evaporation also supplies moisture to the atmosphere, suggesting an increase in precipitation, but the sinking moist air diverges away from the TGD region with no net change in precipitation. This numerical study represents an initial methodology for quantification of the impact of the Three Gorges Dam on the local climate and a more comprehensive, fine-scale set of multi-season simulations with additional observational data is needed for a more complete analysis. **Citation:** Miller, N. L., J. Jin, and C.-F. Tsang (2005), Local climate sensitivity of the Three Gorges Dam, *Geophys. Res. Lett.*, *32*, L16704, doi:10.1029/2005GL022821.

1. Introduction

[2] The impacts of land use change on weather and climate have received increasing attention [e.g., *Cotton and Pielke*, 1992; *Vorosmarty et al.*, 1998; *Xue and Fennessy*, 2002]. Research on the impacts of deforestation of the Brazilian Amazon rainforest on climate have indicated that the local region will lose moisture stored in broad leaves, causing a decrease in evaporation, and an increase in sensible heat and convective precipitation [*Gash and Nobre*, 1997; *Negri et al.*, 2004]. In other locations, urban development has resulted in local heat islands [*Taha*, 1997] and agriculture and overgrazing have caused a number of changes, including the surface roughness, evapotransporation, infiltration, and sensible heating rates [*Pielke et al.*, 1991; *Committee on Scholarly Communication With the People's Republic of China*, 1992]. These land use changes, along with man-made lakes and reservoirs, change the energy and water budgets, affect the regional weather and climate patterns, and frequently have wider impacts.

[3] The Three Gorges Dam (TGD) on the Yangtze River in China represents the world's largest man-made reservoir, with an expected total storage capacity of 39.3 billion m^3, a hydroelectric potential of 84.7 billion kilowatt hours and flood reduction in low lying regions downstream. By 2009, the TGD is expected to fully submerge a 663 km length of the Yangtze River and will have a 1040 km^2 wet surface area, representing a significant land use change in topography and evaporation that is expected to result in changes in the regional weather and climate patterns. Previous studies by the Chinese Meteorological Institute [*Gwynne and Li*, 1992] suggest that the TGD reservoir area will alter local patterns of precipitation, wind, and temperature, and estimate that the annual average near surface air temperature in the vicinity of the TDG will increase by 0.3°C. However, the local climatic impacts due to the change in surface area and weather patterns have not been systematically quantified and are not fully understood.

[4] In this sensitivity study we consider the change in surface characteristics in the TGD area from one of steep vegetated terrain to a large flat saturated surface. This land use change represented here is the largest man made surface with a potential evaporating rate. Here, we investigate changes in local circulation patterns and seek to quantify the relative change in temperature, precipitation, and energy fluxes using a regional atmospheric model coupled to a land surface model.

2. Approach

[5] To quantitatively investigate the relative impact of the TGD land use change on the local climate, two regional climate model simulations, control and the TGD land use change, were generated for the period 2 April to 16 May 1990. This 44 day non-rain period was selected for analysis of the effects of this evaporating surface on the local weather patterns independent of large scale weather, such as monsoons.

[6] The regional climate model used in this study is the non-hydrostatic version on the Penn State/National Center for Atmospheric Research Mesoscale Model Version 5 (MM5) [*Grell et al.*, 1994]. MM5 was configured with 18 vertical layers, the Grell convection scheme to parameterize cumulus clouds [*Grell*, 1993], and the Medium Range Forecast planetary boundary layer scheme to solve boundary layer processes [*Hong and Pan*, 1996]. The Oregon State University Land Surface Model (OSULSM) [*Pan and Mahrt*, 1987] coupled to MM5 by *Chen and Dudhia* [2001a] was used to characterize land surface processes. The OSULSM has 4 soil layers with a total depth of 2 meters and a vegetation scheme advanced by *Chen and Dudhia* [2001b], with the canopy resistance approach of *Noilhan and Planton* [1989].

[7] MM5 was configured with three two-way nested domains at 90 km, 30 km, 10 km. The largest domain (90 km resolution) coordinates are 70E17N by 140E55N, and the smallest domain (10 km resolution) coordinates are 100E26N by 116E34N. The land use change sensitivity

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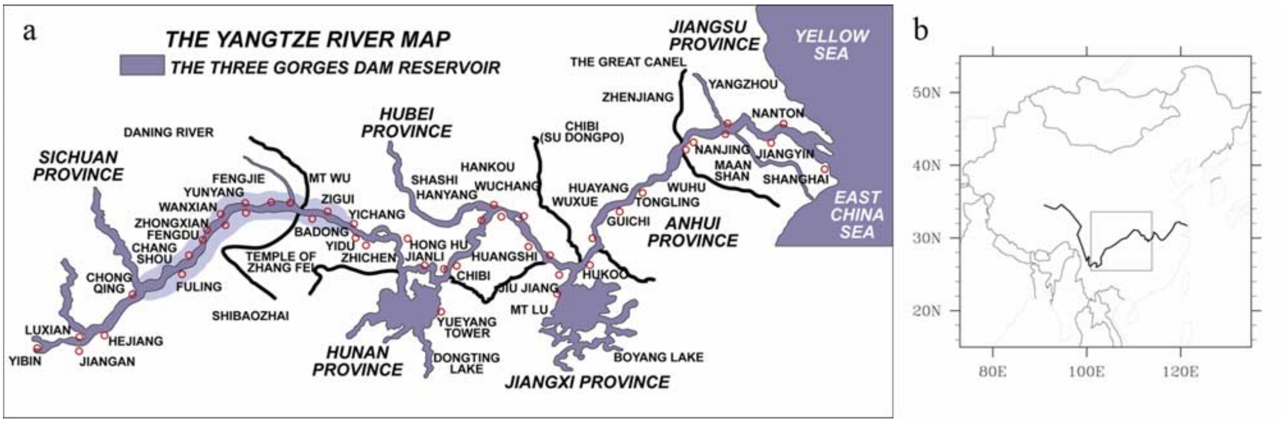

Figure 1. (a) The Yangtze Valley River from Yichang to Chongqing has been simulated as a flat surface within (b) the 10 km resolution nested domain.

carried out for the 10 km resolution nested simulation substituted the Yangtze River Valley area from Yichang to Chongqing with a flat saturated surface area of 1040 km^2 (Figure 1). The 90 km resolution MM5 simulation was initialized and the lateral boundaries were updated every 6 hours using the National Centers for Environmental Prediction/National Center for Atmospheric Research Reanalysis II (Reanalysis) data set. The MM5 output was archived at six hour intervals for analysis.

3. Results

[8] The 2 April to 16 May 1990 time series of the 1040 km^2 TGD area-averaged latent heat flux, sensible heat flux, surface skin temperature, and 2 m air temperature for the relative control and the land use change are shown in Figures 2a–2d. The latent heat flux for this 44 day simulation is consistently higher in the TGD simulation than the control, with difference in values ranging from 15–135 W/m^2 (Figure 2a). The 44-day mean difference is an increase of 79.6 W/m^2, with the largest differences occurring during the warmer days, as would be expected. The energy required for this increase in evaporation is removed from the surface, which lowers the temperature. The surface skin temperature decreased by 1°C to 4.5°C, with a mean increase of 2.9°C (Figure 2c). The 2 m air temperature change is less dramatic, with daily decreases ranging from 1°C to 2.5°C, and a 44-day (Figure 2d) mean decrease of 1.5°C. These temperature differences drive the daily changes in the sensible heat flux, where the control ranges from 5–80 W/m^2 and the TGD change ranges from −45 to 20 W/m^2 (Figure 2b). The 44-day mean change in the sensible heat flux is −48.9W/m^2. The diurnal latent and sensible heat fluxes are most pronounced at mid-day, with the TGD simulation of latent heat increasing by nearly 200 W/m^2 and the sensible heat flux decreasing by 50–75 W/m^2 (Figure 3).

[9] The decrease in the lower level air temperature tends to produce a more stable air mass. The maximum difference in the 850 mb vertical wind speed (i.e. the land-use change minus control) exceeds 10^{-2} m/s along the TGD area (Figure 4), indicating an amplified downward or a weakened upward air mass motion. It is not clear if regions outside of this land use change with rising and sinking motion can be attributed to the TGD impact. To fully understand the spatial range of impact, a much longer

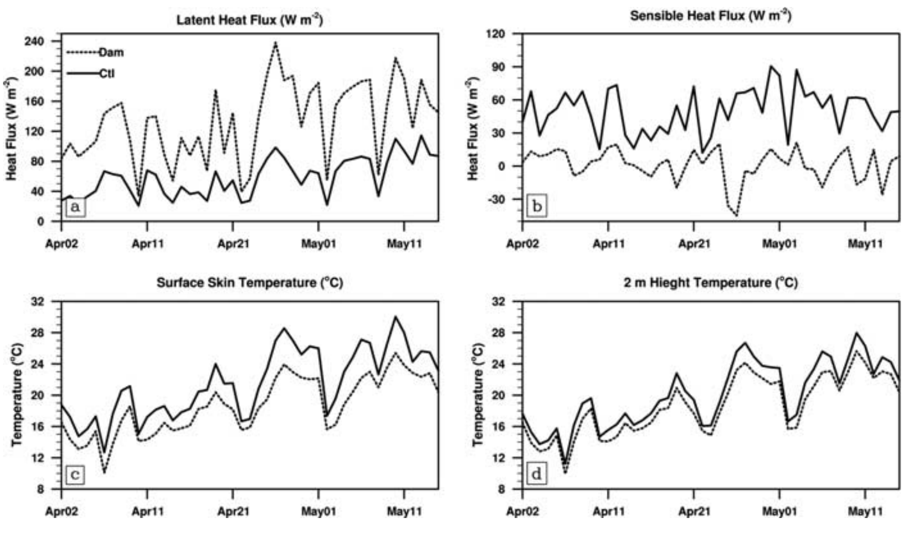

Figure 2. MM5-simulations for 2 April–16 May 1990 indicating a (a) latent heat flux, (b) sensible heat flux, (c) surface skin temperature, and (d) 2 m air temperature, where the blue line is the simulated control and red is the change.

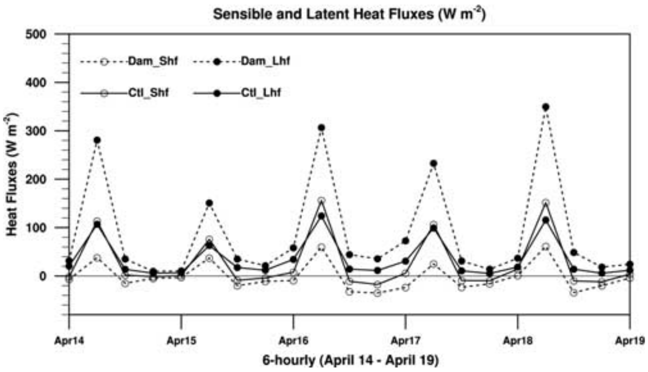

Figure 3. The diurnal latent and sensible heat fluxes for the control (solid) and change (dashed).

simulation that represents a true climate is needed. It is interesting to note that the areas of vertical wind speed change correspond to changes in topography from steep valleys to a flat surface. Figure 5 follows from these results indicating that the sinking air mass brings about a low level divergence of moisture away from the TGD. It can be seen that for areas with decreased upward or intensified downward wind speed, the negative moisture flux divergence in the presence of the TGD is on the order $5-8 \times 10^{-8}$ m/s. This dries the air column above the TGD further, reducing cloudiness, and increasing net surface radiation.

[10] With a reduction in local clouds over TGD, the downward solar radiation increases by 5 to 25 W/m^2 (Figure 6), but the downward longwave radiation decreases by about 1.5 W/m^2 and the precipitation is unchanged (Figure 7). This local radiation shift along Yangtze River valley is well demarcated and there are decreases just beyond the wetted surface area. This leaves an uncertain balance between evaporative cooling and radiative heating, where cooling appears to dominate during the 2 April to 16 May 1990 simulation period. These results are summarized in Table 1.

4. Summary and Conclusion

[11] Two simulations, control and land use change, were performed for an eight week period (2 April–16 May 1990) to determine the net sensitivity of the local climate. The analysis indicates that such a large reservoir acts as a potential evaporating surface that decreases the local surface temperature, and cools the entire atmospheric column, decreasing upward motion, resulting in sinking air. This sinking air mass causes low level moisture divergence, decreases cloudiness, and increases net downward radiation, which tends to increase the surface temperature. However, the evaporative cooling dominates radiative heating resulting in a net decrease in surface and 2 m air temperature. The strong evaporation pumps moisture into the atmosphere, which suggests an increase in precipitation, but the moisture divergence moves this away from the TGD region with no net change in precipitation.

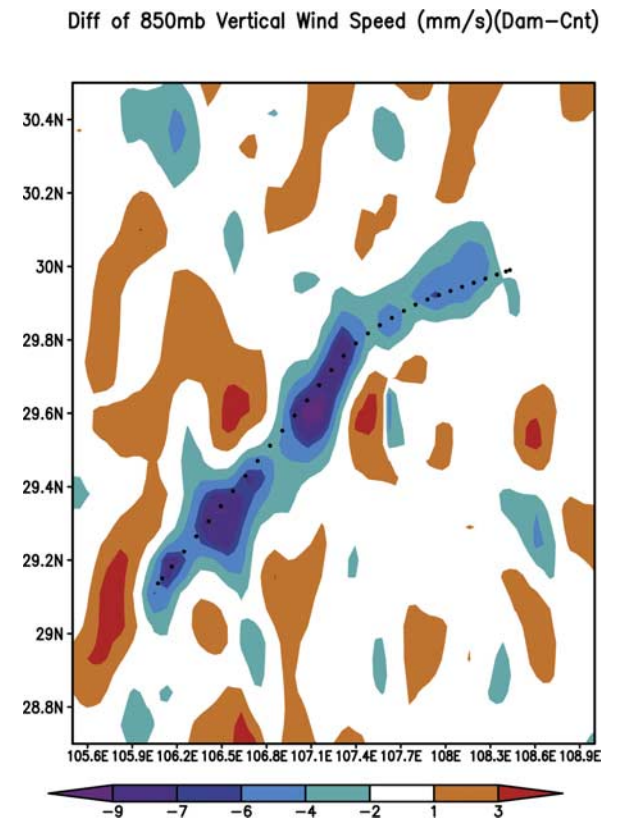

Figure 4. The 850 mb vertical wind speed (mm/s) difference between the change due to the TGD and the control simulation.

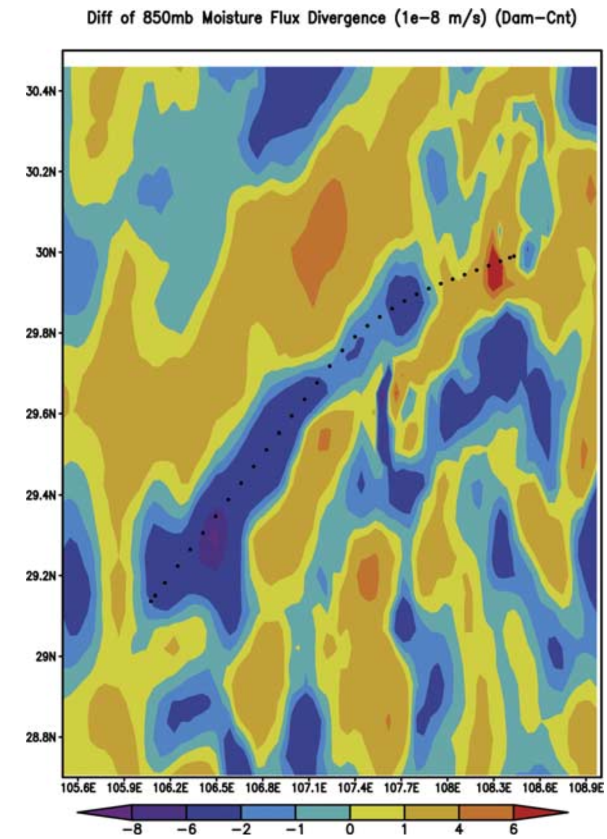

Figure 5. The 850 mb moisture flux divergence (10^{-8} m s^{-1}) difference between the change due to the TGD and the control simulation.

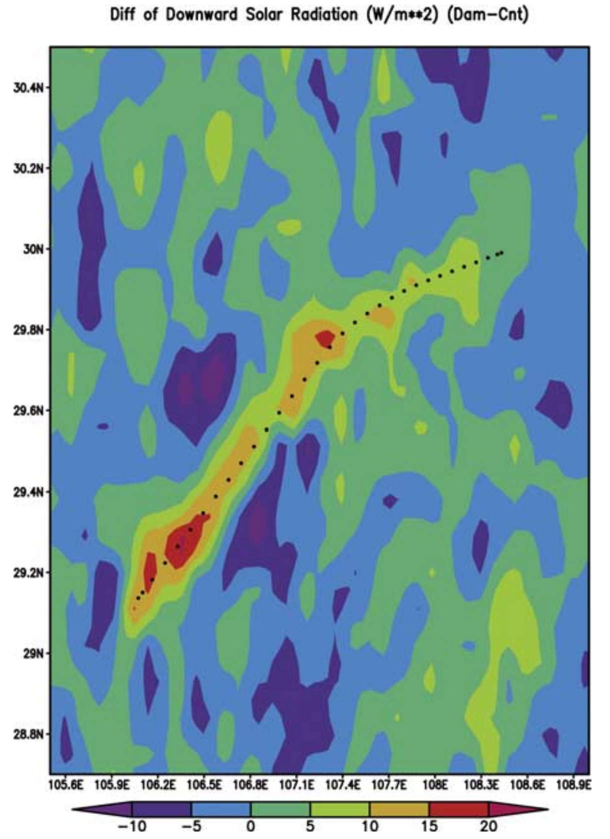

Figure 6. The difference in downward solar radiation with the presence of TGD and without indicated a net increase of 10–25 W/m^2 along the Yangtze River Valley area.

[12] The two processes, increased latent heating with surface cooling, and decreased cloudiness with increased downward solar radiation, are opposing feedbacks that are dominated here by the area-mean surface cooling effect. It is not clear if this holds true for other times of the year when the mean T_{max} is lower and cloudiness may be higher. Furthermore, the impacts on the local monsoon flow, precipitation intensity, and frequency, have not been studied in this initial investigation. However, these relative changes are significant and will likely have an impact on local ecosystems, agriculture, energy, and the population. Simulations at 10 km are not sufficiently fine enough to determine the full extent of this sensitivity and, hence, 1 km multi-year simulations are proposed.

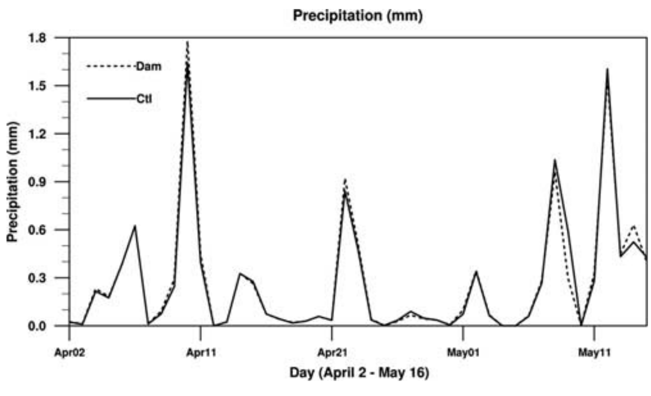

Figure 7. The moisture divergence results in no precipitation change for the simulated TGD.

Table 1. Mean Difference Between the Change and Control

Variable	Difference Value
Surface skin temperature	−2.9 C
2 m height air temperature	−1.5 C
Precipitation	0.003 mm
Latent heat flux	74.2 W/m^2
Sensible heat flux	−48.9 W/m^2
Downward Longwave radiation	−1.5 W/m^2
Downward Shortwave radiation	12.8 W/m^2

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